Technical Memorandum No. 33-81

Investigation of Hailstorm Damage to DSIF Antennas

(Preliminary Report)

Floyd W. Stoller

jpl
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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FIGURES

FIGURES (Cont'd)

I. INTRODUCTION

A study is being made of the probable frequency and severity of hailstorm damage to the ground antennas of the Deep Space Instrumentation Facility (DSIF). The results will be applied in the design of the Advanced Antenna System (200 - 250-ft diameter, 1965) and increased accuracy resurfacing of the present 85-ft antennas.

From September 26, 1961, through November 6, 1961, extensive investigations were undertaken of the probable hailstorm conditions at the DSIF site in South Africa. On completion of these investigations, tests were made as to the effects of the resolved hailstorm conditions on the existing dish surface and on existing panel configurations which might be used as replacements.

This preliminary Report is issued to supply critical information prior to final analysis of all test data. Many of the data available on hailstorm frequency and hailstone size are based on lay-observer* reports, and there are insufficient valid data to afford good statistical values.

II. SCOPE OF PROJECT

The project included:

A. Discussions with cognizant technical personnel, lay-observers, and local residents to determine the probable hailstone

*A member of a body of volunteers, generally local farmers and city administrative personnel. As much as possible, these people are selected for backgrounds in meteorology and/or science. Each person is assigned a specific area by the Weather Bureau on which he reports general as well as unusual weather conditions.

conditions for the South African DSIF site and correspondence with similiar Australian and Goldstone area personnel, to resolve the hailstorm conditions at the sites.

B. Development of a test plan based on the information obtained in (A) above, which would provide adequate information as to the probable effects of the various hailstorm conditions on existing antenna panels or possible replacements.

C. The procurement of the necessary test equipment, hailstorm-simulation hardware, and test panels to implement (B) above.

D. The establishment of a test location and completion of the tests.

E. Reduction and analysis of the experimental data.

F. Preparation and presentation of a preliminary and a final report on the project.

III. HAILSTORM CONDITIONS - SOUTH AFRICAN DSIF AREA

Discussions with personnel at the National Building Research Institute of the South African Council for Scientific and Industrial Research (CSIR) at Pretoria, the National Weather Bureau Center at Pretoria, the Weather Bureau field personnel in the Krugersdorp DSIF area, DSIF site personnel, and DSIF area residents and nearby farm personnel have afforded the following information:

A. There exists in the DSIF area a region in which hailstorms are prevalent, known as the "Pretoria Hail Belt." This region produces an average of five hailstorms a year, one or more of which are classified as severe.

B. The DSIF site is definitely in the path of the "Pretoria Hail Belt."

C. The hailstorm classification of severe is defined as a storm in which the average hailstone has a diameter of 3/4 in. or greater.

D. Hailstorms with hailstones of an average diameter of 1/2 in. are known to produce hailstone densities of between 75 and 400 hailstones in a 5 x 5-in. square. This density level decreases with increase in hailstone diameter. It is estimated (based on the statements of lay-observers concerning the Pretoria storm of 1949) that for storms producing very large hailstones (2 1/2 to 3 in. in diameter), the density is between 10 and 50 stones in a 5 x 5-in. square. These density levels are for average hailstorm durations of 10 to 20 min.

E. While storms are classified by a rough estimate of the average hailstone size, this does not imply the absence of larger stones. All storms seem to produce larger stones, or aggregates, mixed in with those of average size. Information in this area is skimpy; but the information that does exist, plus the general subjective impressions of lay-observers, indicate the following:

1. Every hailstorm produces scattered stones and aggregates with diameters greater than the average by factors of 2 to 3 in general, and occasionally up to 5.

2. The distribution of these stone sizes seems to fall approximately as follows:

40% to 70%	average for storm
15% to 25%	larger by factor of 2
15% to 25%	larger by factor of 3
5% to 10%	larger by factor of 4 and 5 (This group may not occur at all.)

F. Hailstorms have occurred at the exact location of the South African DSIF antenna in the 1958-59, 1959-60, and 1960-61 hail seasons at least twice each year. Estimates by lay-observers of hailstone diameters for these storms were between 1 and 1 3/4 in.

G. Hailstorms for the "Pretoria Hail Belt" region seem to have radii of 2 miles, and the general storm area has radii of 4 miles. The center of the hailstorm appears to move with an average velocity of 15 mph.

H. The average duration of a storm, for a given point on the ground, appears to be between 10 to 20 min. These storms are generally accompanied by winds of velocities between 30 and 60 mph, with gusts of 30 to 50% of the average value.

I. The general hailstorm season is mid-October to mid-April, with an intensity peak during December and January. Hailstorms have occurred as early as the first part of September and as late as May.

J. It appears that extremely severe hailstorm seasons (where the average hailstone size is 2 to 3 in. in diameter) have an 8- to 12-year cycle, and/or are accompanied by unusually dry periods before and at the start of the hailstorm season. This is an assumption by CSIR - Pretoria Weather Bureau and is based on very limited data.

A telegram message received November 7, 1961, from Mr. D. Hogg (station manager, DSIF South Africa) disclosed the following: "On November 7, 1961, a hailstorm, producing hailstones the size of tennis balls, missed the site by a short distance."

Since the last occurrence of such extremely large hailstones was in 1949, and as the first part of this year's hail season has been characterized as extremely dry, some weight seems to be afforded the CSIR - Pretoria Weather Bureau assumption that extremely severe hailstorms may have a 12-year cycle and that severe hail seasons are preceded by abnormally dry periods.

K. The Weather Bureau is unable to predict hailstorms but can predict when thunderstorms of the type which may produce hailstorms will occur.

L. The topography required to afford collimation-tower location and RF shielding for DSIF antenna sites is the type conducive to the production of hail.

IV. HAILSTORM CONDITIONS - OTHER DSIF AREAS

The current information on the possible hailstorm conditions at the other two DSIF areas is fairly limited. Contact has been made with the cognizant personnel in these areas, but as yet, little information has been received. Details on these areas will be presented in the final report.

A. Woomera DSIF Area

Hailstorms do occur in the Woomera DSIF area. Correspondence with Woomera personnel discloses that in 1958, a hailstorm occurred in the village of Woomera; this storm broke windows on the south side of homes, dented cars, destroyed roofs of asphalt composition, dented and tore corrugated aluminum roofs, and levelled all flowers and other garden plants.

Although specific information is not yet available, the damage suffered implies hailstones with diameters of 1-1/2 in. or larger. The fact that windows on the south side of homes were damaged indicates that the storm could have passed over the DSIF site, since the site is located south of the village.

B. Goldstone DSIF Area

It has been established that mild hailstorms occur at Camp Irwin on an average of twice a year. The hailstones produced by these storms have diameters of about 1/4 in. and are of a fairly soft composition. However, severe hailstorms (hailstone diameters between 1 and 1-3/4 in.) did occur in 1957 and 1959 at Barstow, California. The prevailing winds during the hail season are from the South or Southeast. Since Barstow is south of the DSIF site, the implication is that the storms which produced these large hailstones probably passed over the site. While no data are available yet to affirm the past occurrence of severe hailstorms at the DSIF site, the inference is that such a possibility exists.

V. TEST PLAN AND PROCEDURES

Based on the information of Section III, the following general test plan and procedures were developed:

A. Test Plan

1. To impact test panels similiar to those existing on the 85-ft antennas, or types available as substitutes, with hailstones of various sizes, for the average wind conditions and minimum densities which might be experienced, and with a random pattern.
2. To impact one panel of each type with single or multiple stones stones at specific points.

B. Procedures

The test procedure for the random-pattern impacted panels was as follows:

1. Photograph a panel prior to impact, visually inspect its surface, and measure the depth of any specific surface defects; then measure the conformity of the surface to a paraboloidal surface by means of the "parabola test fixture."
2. Impact the panel surface in a random pattern with a hailstone of a specific size at the expected wind conditions and minimum hailstone density.
3. After impact, photograph the panel surface, inspect it visually, and measure the depth of any specific surface defects; then measure the conformity of the surface to a paraboloidal surface of revolution.
4. Repeat steps (1), (2), and (3) for hailstones of increasing diameters up to the maximum expected hailstone size, or to the point of panel-surface destruction.

The test procedure for the panels to be impacted with specific position-related hailstones of sequentially larger diameters was as follows:

1. Mark off specific areas on the panels with circles of red paint.
2. Impact the specific areas of step (1) with hailstones of sequentially larger diameters in the following pattern: one hailstone of 1/2-in. diameter in the first circle, three hailstones of

1/2-in. diameter in the second circle, one hailstone of 3/4-in. diameter in the third circle, three hailstones of 3/4-in. diameter in the fourth circle, etc., up to a diameter of 3 in. Carry out this pattern for a no-wind condition and a wind of 45 mph.

3. Photograph damage to panels and return panels to the Jet Propulsion Laboratory (JPL) for further measurements and inspection.

VI. TEST SITE, EQUIPMENT, AND PANEL TYPES

The experimental tests were performed at the South African DSIF site. The test equipment required included the parabola test fixture, test-fixture recorder, precision steel rules, and a polaroid camera with film. These were supplied by JPL.

The hailstorm-simulating equipment included a gas-operated hailgun, nitrogen gas bottles, ice saw, ice drill, hailstone ice mold, precision scale for weighing hailstones, and a deep freeze for storing hailstones. This equipment was supplied by CSIR - Pretoria.

The antenna panels used for the test were supplied by JPL, and consisted of the following variations of the basic Blaw-Knox Co. (B-K) 85-5 panel:

A. Four B-K expanded aluminum-screen-surfaced panels.

B. Four B-K perforated aluminum-plate-surfaced panels.

C. Four B-K solid aluminum-plate surfaced panels.

D. Four Rohr Aircraft Co. (RAC) honeycomb-core solid-aluminum-plate-surfaced panels.

VII. TEST PREPARATIONS

A test site was set up in the rear of the hydromechanical building. The hailgun and its platform, ice drill, gas bottles, and panels were set up outside; the parabola test fixture, its recorder, ice mold, scale, and deep freeze were set up inside. Figure 1 presents an over-all view of the test site and associated equipment. Figure 2 shows the hailgun being fired against a solid surface panel, the operational personnel, and the test set up. In Fig. 3, a panel is measured for surface damage by means of the parabola test fixture, and Fig. 4 illustrates the hailstone mold with an ice slug being formed on the right, a completed hailstone being weighed on the left, and a closeup of the parabola test fixture measuring a panel for surface damage.

VIII. PRELIMINARY TEST RESULTS

The information presented here is based only on visual inspection of the panels and hand measurements of specific hailstone surface damage (dents, breaks, etc.). The complete data from the parabola test fixture and the position-referenced impacted panels will not be available until publication of the final report. Also, the following information is based on impacts whose velocities include a velocity component contributed by a 45-mph wind.

A. Panel Surface - Expanded Aluminum Screen

The tests show that a hailstone of 1/2-in. diameter will cause a surface dent of 1/8 in. or greater. This surface damage increases up to a depth of 1-1/2 in. with increasing hailstone diameters. When the hailstone diameter reaches between 1 and 1-1/2 in., the surface is torn and holes occur. Figure 5 shows a panel impacted by 1-1/2-in.-diameter hailstones.

B. Panel Surface - Perforated Aluminum Plate

The tests show that for hailstones of diameters below 1/2 in., the perforated plate is not damaged. A 1-in. hailstone produces a 1/16-in. dent or greater; the surface damage increases to a depth of 1/2 to 3/4 in. when impacted by 2- to 2-1/2-in.-diameter hailstones. The plate cracks and some holes appear when impacted with hailstones of diameters between 2-1/2 and 3 in. Figure 6 shows a position-related impacted panel. The holes in the lower right were produced by 3-in. hailstones. The third circle on the upper right-hand side shows a crack which was produced by a 2-1/2-in. hailstone.

C. Panel Surface - Solid Aluminum Plate

The tests show no damage for hailstones of diameters below 3/4 in. A hailstone of 2-in. diameter produces a dent with a depth of 1/16 in. or larger. This surface damage increases to depths of 3/8 in. with increasing hailstone size to the maximum expected diameter; no cracking or tearing of the surface ever occurred. Figure 7 shows a position-related impacted panel. Dents are evidenced in the lower three right-hand circles and three middle circles.

D. Panel Surface - Honeycomb-Core Aluminum Plate

The tests show that impacts by 1/2-in.-diameter hailstones produce dents of 1/64 to 1/16 in. This surface damage increases to depths of 1/2 in. with increasing hailstone size to the maximum expected diameter. While no cracking or tearing of the surface ever occurred, the multiple impacts on the panel caused the surface plate to separate from the honeycomb core. Figure 8 shows a panel impacted by 1-1/2-in. -diameter hailstones at the expected density; dents run from 1/16 in. for 1/2-in. hailstones to 1/2 in. for 3-in. hailstones.

For expanded aluminum screen and perforated aluminum plate (see A and B above), holes and breaks occur at lower levels when the impacts occur adjacent to a support member.

Based on preliminary data taken from the position-impacted panels, the curves of Figs. 9 and 10 were compiled. These Figures show the deviation of the surfaces of the panels from a paraboloid for single and multiple hailstone impacts and for no wind and 45 mph winds, on all four types of panels.

The "honeycomb" panel curve is deceptive in that, on cutting open the panels, it was discovered that the actual dent (as indicated by the crushed core, Figs. 11, 12, and 13) was greater than indicated by the surface measurements.

Figures 11, 12, and 13 show that the surface plate and core have delaminated and the surface plate has partially sprung back, indicating less surface damage. When delamination did not occur, the surface damage was comparable to core damage for similar impact energies. As future panels would necessarily have a more positive bonding to prevent eventual delamination of the whole surface plate, it is apparent that the "honeycomb" curves of Figs. 9 and 10 would be worse by a factor of perhaps 2 to 3.

IX. CONCLUSIONS BASED ON INFORMATION COLLECTED TO DATE

A. At least one severe hailstorm a year can be expected at the South African DSIF site (severe referring to a storm whose average hailstorm diameters are 3/4 in. or larger).

B. Severe hailstorms may be expected at the Woomera DSIF site. The possible frequency of occurrence has not yet been established.

C. Severe hailstorms may occur at the Goldstone DSIF site; but in the light of existing data, it does not seem likely.

D. If a severe hailstorm occurs at any of the sites, it will critically affect the surface of the existing antenna panels (see Figs. 5 and 6).

E. In a severe hailstorm, hail damage of unresolved levels will occur to such hardware as feed assemblies, waveguide, drive-system components, readout-system components, electronic-cage hardware, warning and structure lighting, optical tooling, and boresight instrumentation.

F. A surface panel can be developed which will survive the expected hailstorm conditions.

G. As the topography required for the DSIF sites is conducive to hailstorm creation, the problem, while it may be minimized, will not be removed by relocation.

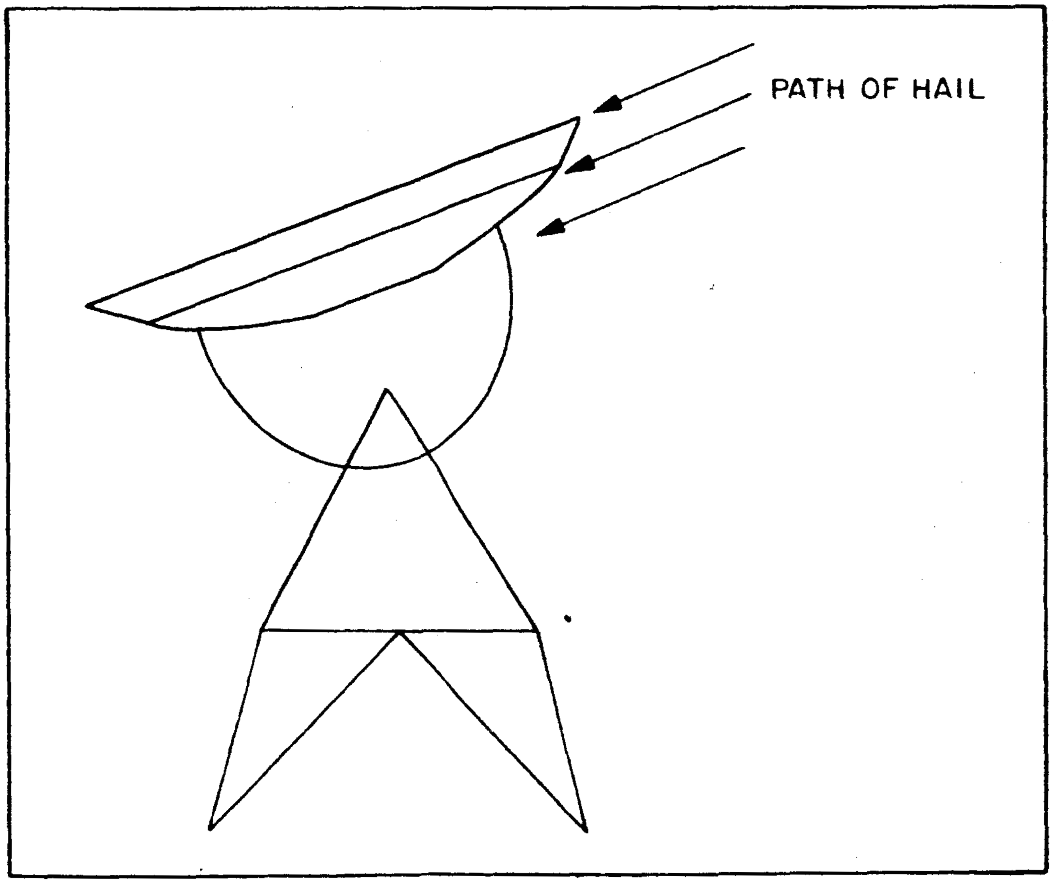
H. Of the available panel types, the solid aluminum-plate surface appears to be the best; however, while it will survive a severe hailsotrm without destruction of its surface, it will not maintain its required surface tolerance.

X. RECOMMENDATIONS

In the light of the preliminary results presented here, the following recommendations are made:

A. Immediate Action

1. DSIF personnel located on site should be instructed to position the antenna so as to incur a minimum amount of damage from a hailstorm. This can be accomplished by turning the edge of the dish as nearly as possible into the path of the hail. It is believed that this action may limit the damage to one side of the dish only (see Sketch 1).



Sketch 1

2. Paraboloidal shoes of aluminum and lead and wooden mallets should be provided for the African and Australian sites. Then, if hail damage occurs, the dish surface may be worked back into shape much the way automobile bodies are restored.

3. The items listed in Section IX E should be protected with shielding where possible. It appears that the shielding must be of 1/8-in. aluminum or heavier.

B. Future Action

1. Develop a hailstorm test facility at JPL in the form of a hailgun, ice drills, hailstone molds, hailstone storage and stabilization equipment, and test-panel positioning rack.

2. Carry out an investigation to develop a panel which will survive the expected hailstorm conditions and maintain the required surface accuracy; also, provide design information for hailstone-proofing other critical components on the DSIF antennas.

C. Continue analysis of frequency and intensity of hailstorms in the DSIF station locales and survey all other possible means of avoiding hailstorm damage (such as weather control, etc.).

D. Depending on the results of A, B, and C above, be prepared to install the developed panels on the Australian and South African antennas prior to the next hailstorm season and implement whatever protective measures appear apropos for antenna elements other than face panels.

E. Continue investigation of relation between surface characteristics and radiofrequency performance of large reflector antennas.

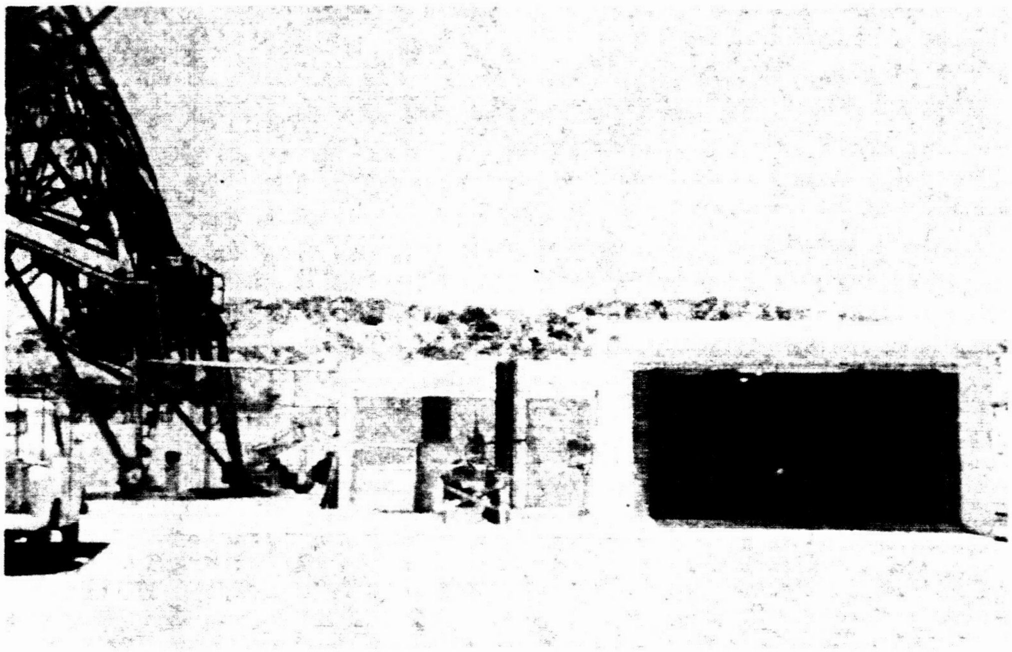


Fig. 1. South African DSIF hailstorm test site

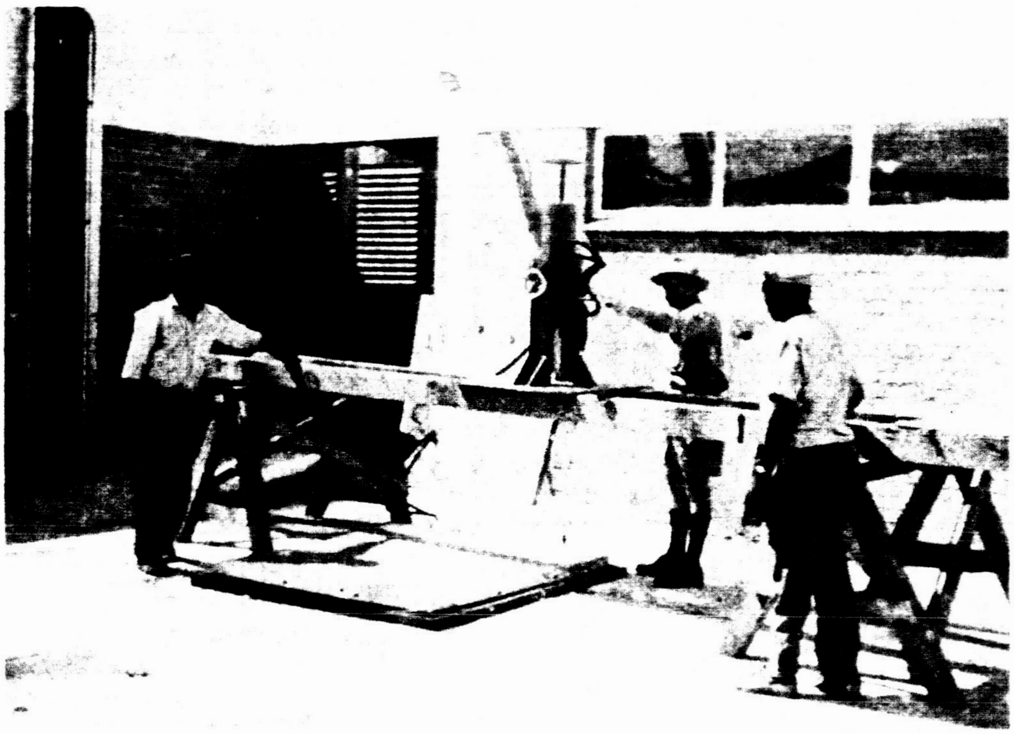


Fig. 2. Hailgun being fired against solid-surface panel

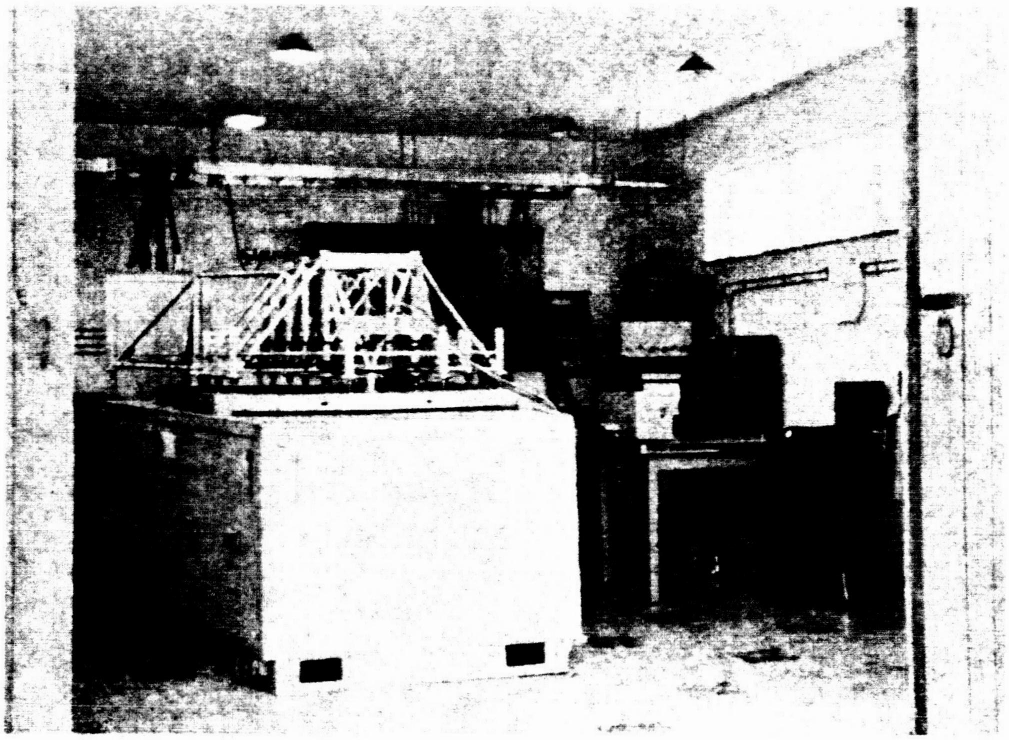


Fig. 3. Damaged panel being measured with parabola test fixture

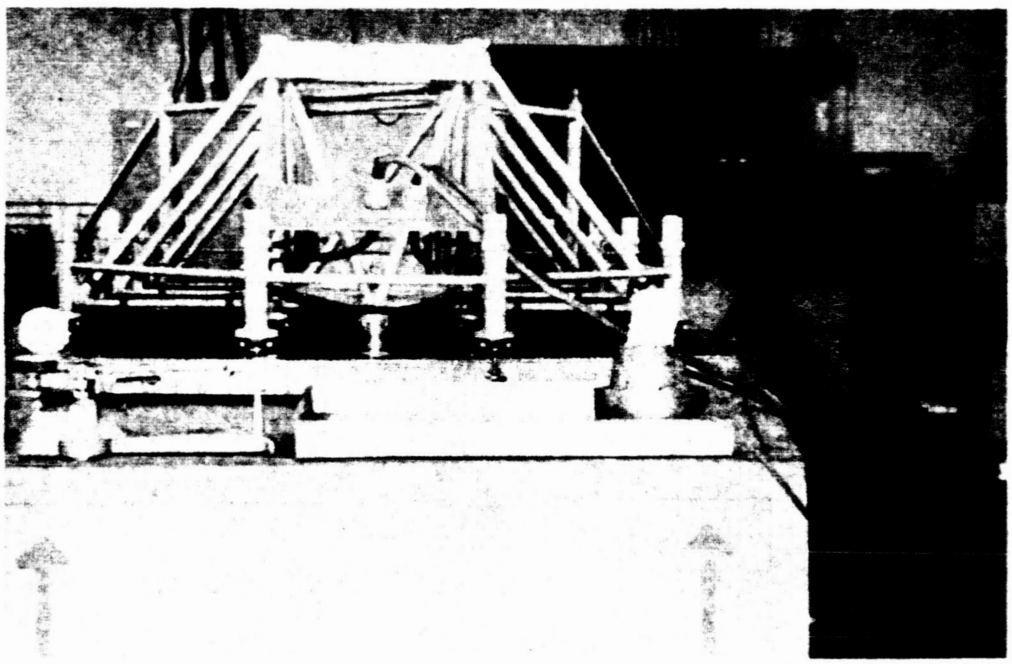


Fig. 4. Parabola test fixture measuring damaged panel, ice slug in hail mold on right, finished hailstone being weighed on left

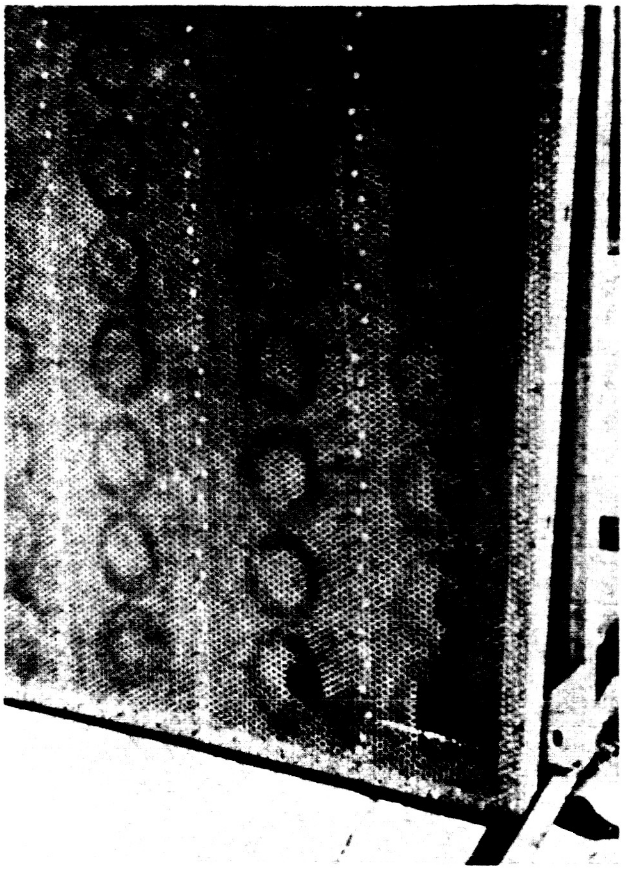


Fig. 5. Expanded aluminum-screen-surfaced panel after hailstone impacts

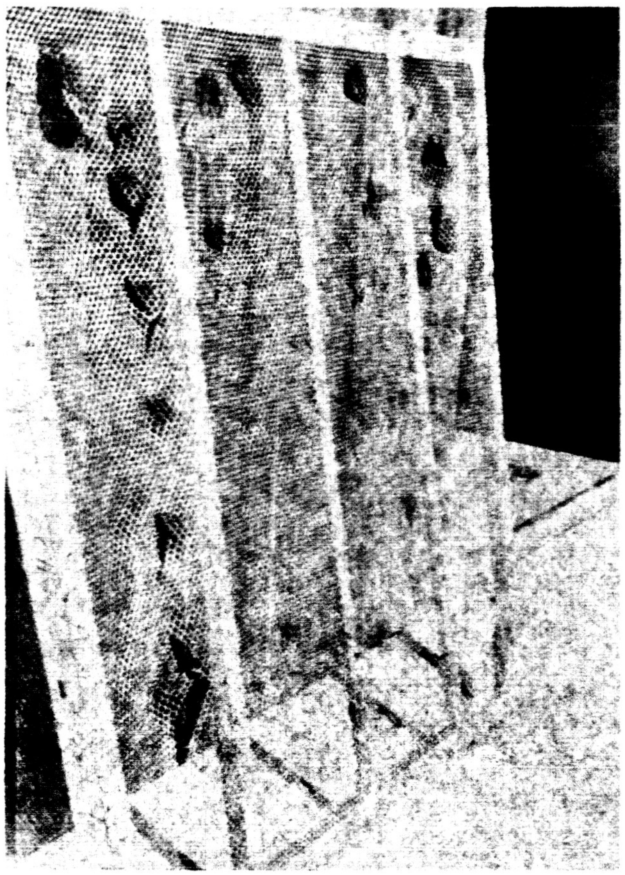


Fig. 6. Perforated aluminum-plate-surfaced panel after hailstone impacts

Fig. 7. Solid aluminum-plate-surfaced panel after hailstone impacts

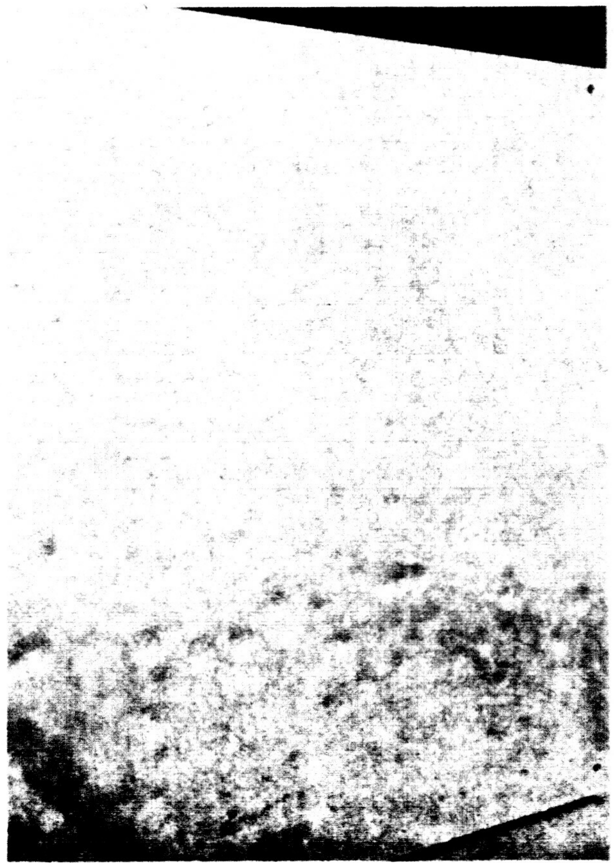


Fig. 8. Aluminum-plate honeycomb-core panel after hailstone impacts

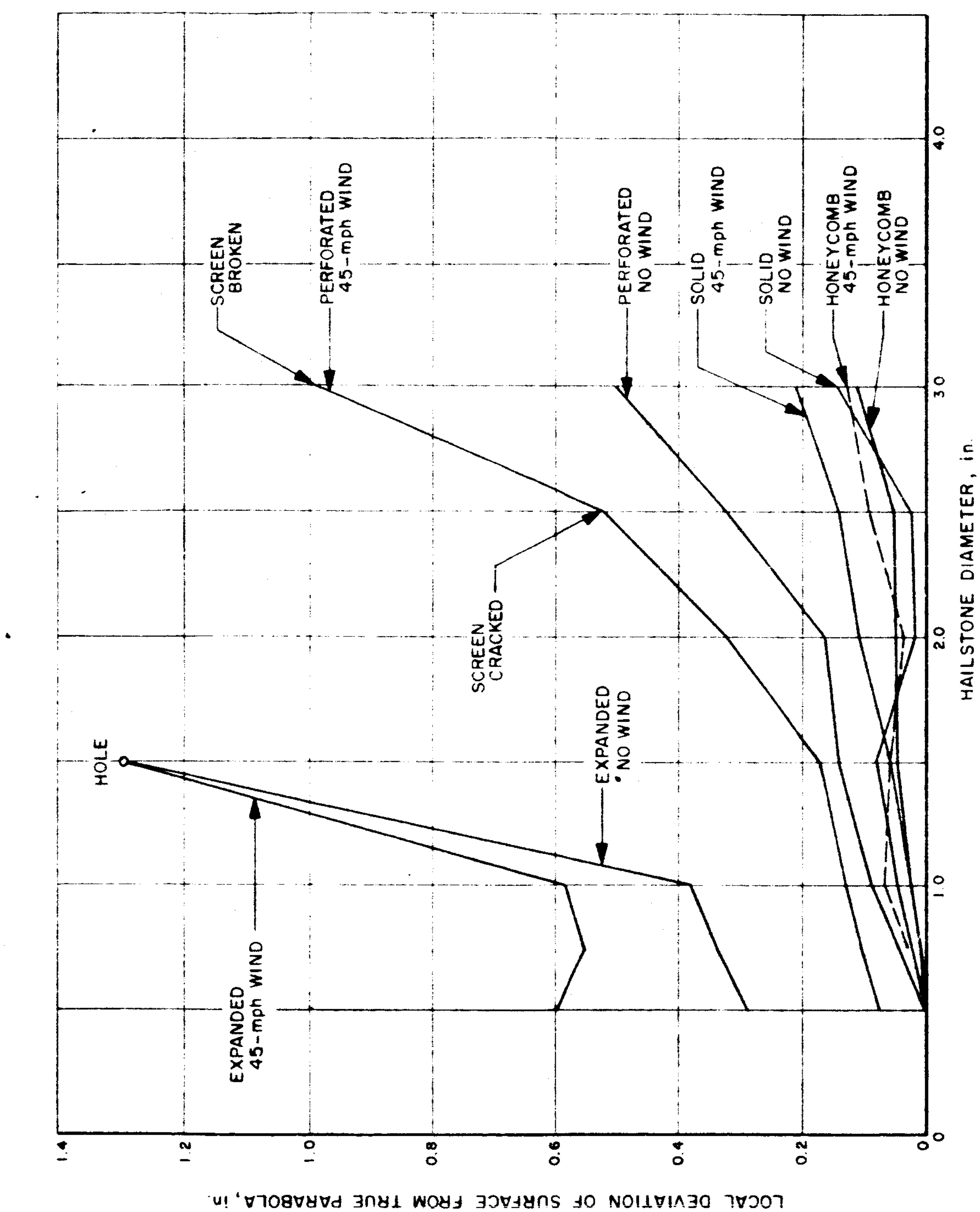


Fig. 9. Single impacts

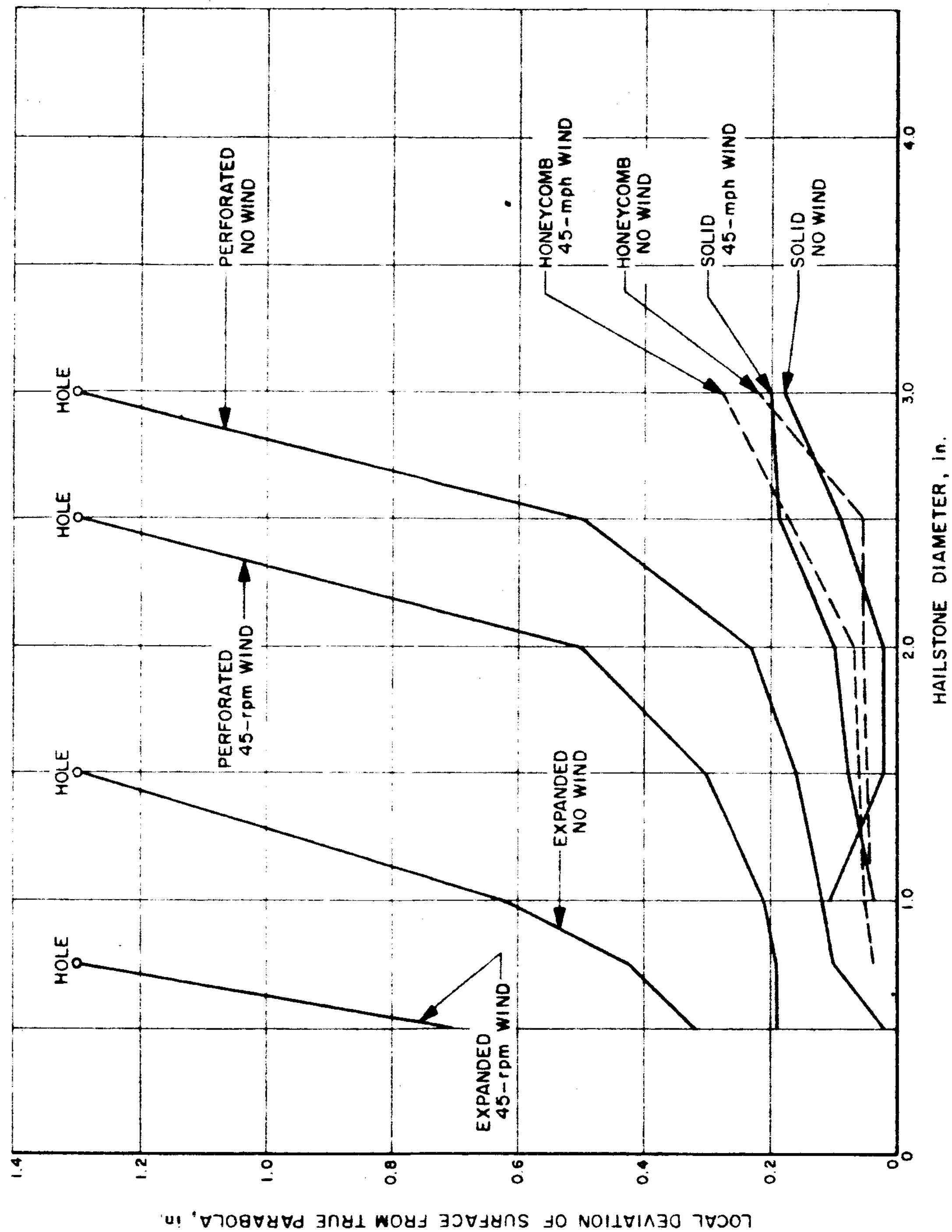


Fig. 10. Multiple impacts

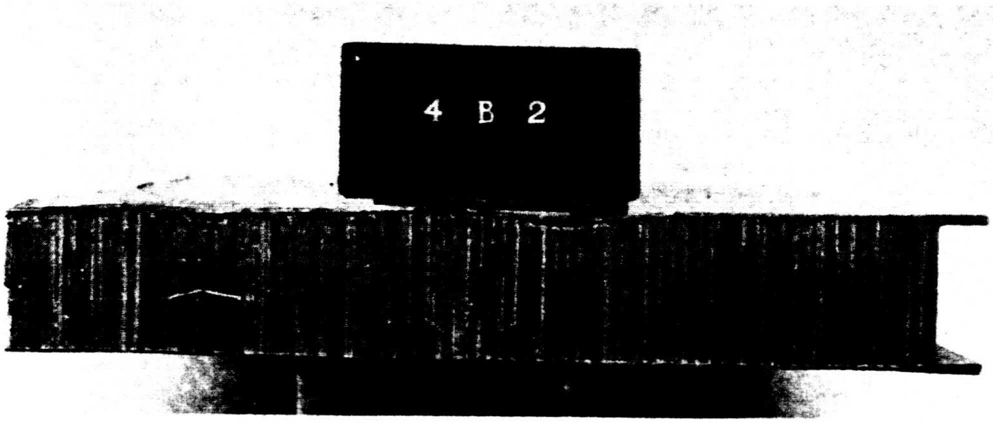


Fig. 11. Sectional view 4H2 of aluminum-plate honeycomb-core panel after hailstone impacts

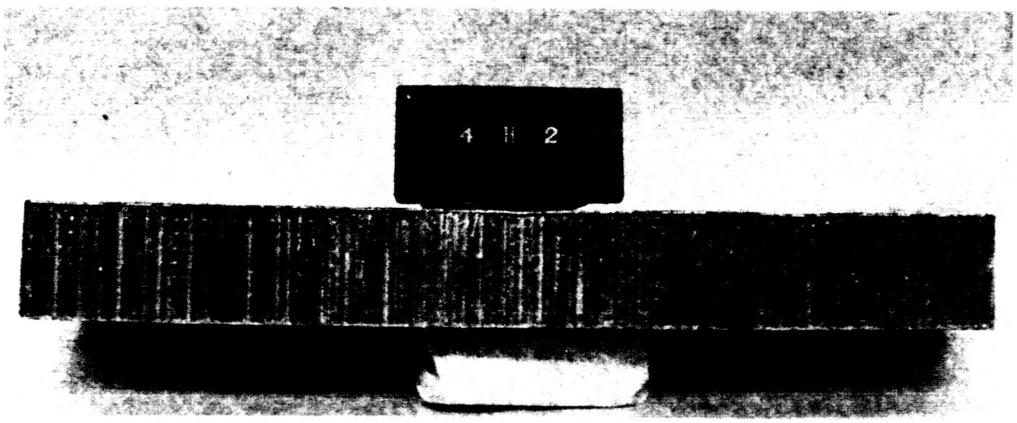


Fig. 12. Sectional view 4B2 of aluminum-plate honeycomb-core panel after hailstone impacts

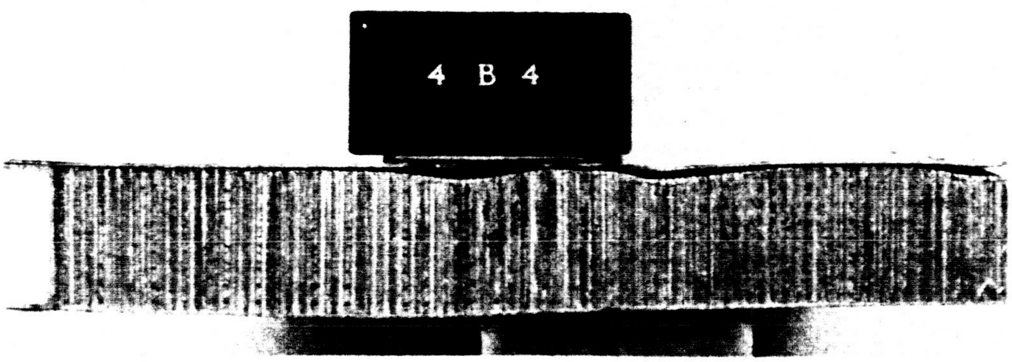


Fig. 13. Sectional view 4B4 of aluminum-plate honeycomb-core panel after hailstone impacts

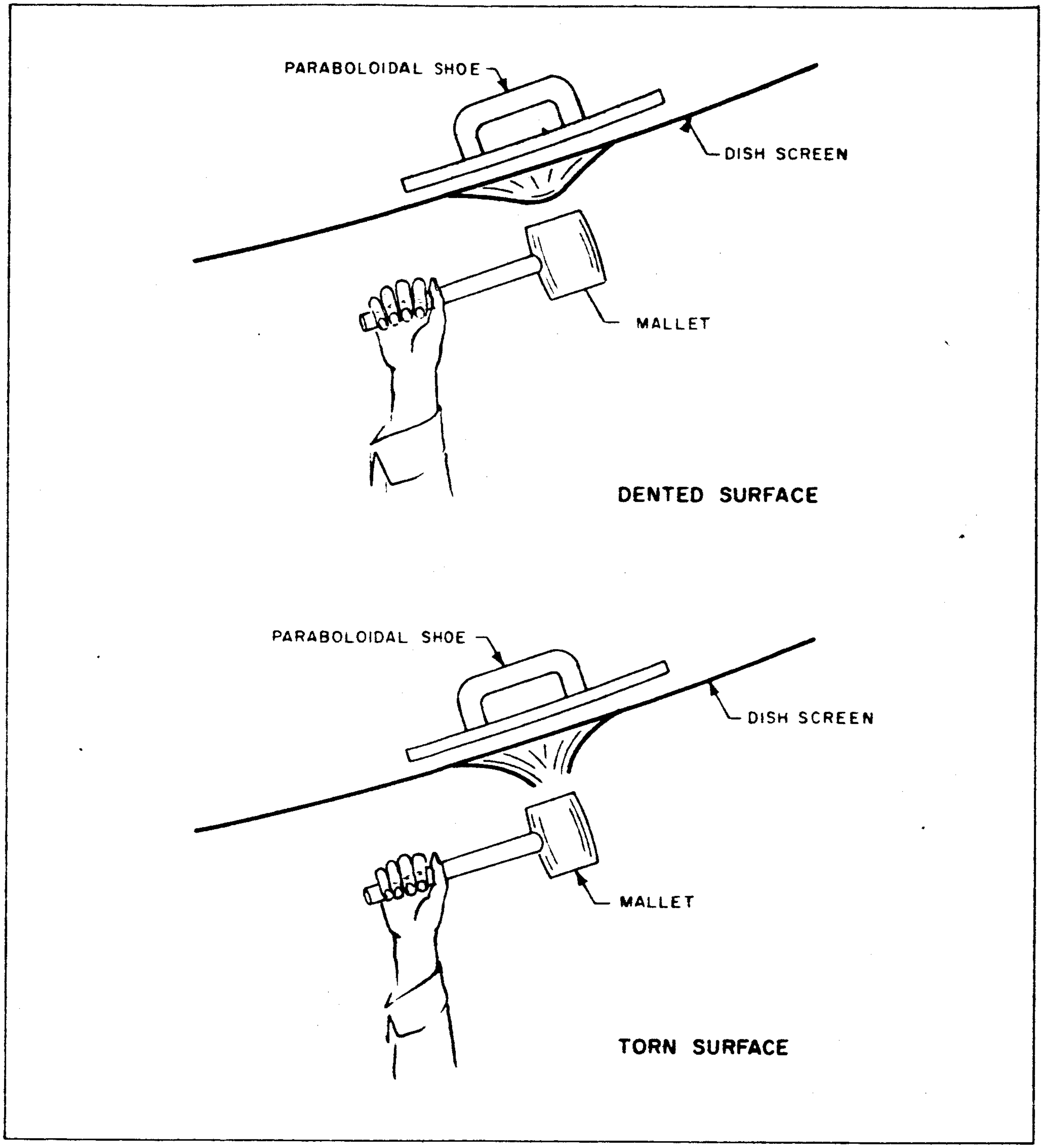


Fig. 14. Damaged panel surfaces being repaired with paraboloidal shoe and mallet